Chapter 5

Cement Standards

CEMENT STANDARDS

1. INTRODUCTION

1.1 Importance of Standards

In many of our daily activities we are unconsciously confronted with standards.

When we go to see a football game at 3.30 p.m. we seldom realize that if it really begins at the scheduled time it is simply because we have standardized our time according to fixed rules. Then, it is up to us to decide buying an expensive Swiss watch in case we look for a reliable product, proven to keep its conformity to the time standard long enough.

Many other less trivial examples could be reported to witness to what extent our life is defined and conditioned by standards of any type (mainly moral...).

We need standards because they are the way we have to fix generally valid and accepted rules to measure and compare things with one another and so define the relationship between "producer" and "consumer".

Producing according to an official standard means then putting on the market a product of well defined, measurable and recognizable characteristics.

This will positively affect the producer's position with respect to own customers in terms of reliability, confidence and commercial relationship and will protect him against unfair competition and undue complaints.

The consumer is then assured that by using a standardized product he can rely on a market-conforming, well defined and reasonably constant quality product, that will reflect in a consistent and cost-effective production.

The designer and contractor will be provided with confidence about the essential material characteristics they need to design and execute the desired structures.

It is therefore of vital importance that cement and concrete producers be aware of the expected developments of own standards and, if needed, take the necessary actions to influence development in the desired direction, be it through either direct or own association's involvement.

1.2 Development of Standards

Developing a standard is not an easy deal. From previous comments, it should be clear that a product standard involves both the producer' and the consumer's interests and this is not an ideal starting point to find rapidly an overall agreement on the standard objectives.

On the other hand, standards can meet easy and widespread acceptance only when all parts involved participated in its development.

Standards shall then be a common elaborate of

- the producer
- the seller
- the consumer
- the designer
- the official testing institute
- the universities or research laboratories
- the government.

They should also be conceived (and periodically revised) taking into account

- the present technical situation of the industry
- the need of progress for the country
- an effective environmental compatibility (energy saving and by-products recycling)
- all technical improvements and economic changes that took place from the last edition
- modified market exigences and demands
- last but not least, the effort to pull down trade barriers in large State federations.

2. CEMENT STANDARDS

2.1 Product Standards

Product standards, which we are mostly interested in, are usually meant to define

- ♦ the quality of a product, in terms of composition, performance and application (i.e. the European ENV 197-1 standard on common cements)
- ♦ the common rules for uniformly testing and assessing the prescribed product quality (i.e. the associated EN 196 series of testing methods)
- ♦ the conditions for the use of the product in particular applications (i.e. recommendations for durability of concrete structures, a.s.o.).

They include classification, composition, specification and compliance criteria. As regards specification, that is a statement of one or a set of requirements the material shall comply with, they can be prescriptive- or performance oriented.

The prescriptive specification defines a product according to its composition, the performance specification defines a product according to its function in application, thus products of different composition can comply.

It is rather difficult to say which is better. On one hand a performance standard is supposed to be tightly related to the product's field performance and should better represent its ability to fulfill the customer's expectations and needs. On the other hand, assessing particular properties can involve use of complicated and time consuming testing methods; sometimes even the correlation between lab testing and field performance is still to be demonstrated. Then, in many cases, an easy prescriptive standard (i.e. maximum C_3A for sulfate resistance) is preferred.

We should not forget anyway, that some of the specifications for cement rely on performance testing, such as setting time and strength.

In the case of cement, product specifications take into account

- ♦ production aspects, as regards raw materials availability, plant design, environmental needs
- ♦ application aspects, as regards experience of use, available technology, needs of differentiation, customer expectations
- ♦ marketing aspects, as regards cost effectiveness of products, principles for fair competition, appropriate price/quality differentiation
- ♦ quality aspects, by setting minimum and/or maximum acceptable values for most of the standardized properties, as a protection against dangerous behaviour of non-conforming products.

Some of the most recent international standards (e.g. ENV 197-1 on common cements) now include also a chapter on conformity evaluation.

This is a very innovative and clever approach to product standardization, since it introduces statistical tools to evaluate quality, not simply in terms of fulfilling absolute limit values, that are still considered as threshold values for conformity, but mainly taking into account the characteristic values, that include calculation of mean value and standard deviation of the measured property. An example will be given in the following pages.

After highlighting the merits of standards, we cannot help mentioning their main drawback. Product standards are capable to depict the present situation and technology only, without being able to forecast, and open paths for, technical development. This sometimes reflects in a serious hurdle to innovation, since a real new product will hardly find a corresponding standard to be referred to.

This is a strong argument for those people who are in favour of performance standards, that hinder technical progress much less than prescriptive ones.

Standardization bodies should therefore find the right balance and make their mind more progress-oriented, so to walk aside innovation and not run after it.

2.2 Significance of Specifications

We have seen that a specification is a requirement the product shall comply with. But why are these requirements specified?

The main concern in a cement standard is that the binder has to be used in constructions where safety, comfort and durability must be safeguarded. Additionally, special applications need special cement properties that have to be adequately described in specifications.

In the following, a series of examples indicate properties that are specified for cements and also the inconveniences they must prevent; as mentioned, requirements can be related either to cement composition or to performance.

- minimum setting time - to prevent early or flash setting of cement, that would excessively shorten the life time of the fresh and workable blend;
- soundness (Le Chatelier or autoclave test) - maximum expansion is specified to prevent the risk of cracking in hardened structures;
- maximum SO_3 content - same as above;
- maximum C_3A content - to limit reactivity to sulfate attack and heat development of cement;
- maximum C_3S content - to limit reactivity to pure water attack and heat development of cement;
- maximum heat of hydration - to prevent excessive heat development;
- compressive strength - to guarantee a minimum strength development in properly designed concretes and cementitious blends;

and so on.

2.3 Testing Methods

Product standards usually deal with the characteristics of a product, making reference to the proper testing methods to be used for the assessment of these characteristics.

Standards about testing methods aim at defining uniform conditions under which the product is tested.

They fix the product's testing conditions, in the case of cement if the measurement of the property will be carried out on

- powder
- paste
- mortar
- concrete;

they define

- scope of testing
- referenced documents
- testing apparatus
- reactants
- calibration of apparatus
- testing procedure
- calculation of results
- reporting
- precision and bias of the method.

As for product specifications, the purpose is to have a common tool to evaluate the product and reproduce the results obtained by different testers with reasonably narrow deviation. So, a product with a wide (even transnational) market distribution can be checked in different places with sufficient confidence on the accuracy and reliability of results.

This is clearly assuming a growing importance in the view of free trade activities, but the most practical advantage for a plant technologist is to use the same language and the same criteria to identify products and properties.

Drafting testing methods is usually easier than for product specifications, because it does not involve commercial and political issues, nevertheless some main principles should be observed. A testing method should be

- ♦ reliable (repeatable and reproducible) and meaningful
- ♦ able to allow easy correlations between results and product characteristics and/or properties
- ♦ easy to be implemented in any official as well as plant laboratory
- ♦ as far as possible not hazardous to workers or environment.

Most of the main testing methods for cement are well established standards. If a new property needs to be measured, then a working group is usually formed and a draft test is issued; the following round-robin testing will prove the effectiveness of the method to transform it into an official standard.

3. INTERNATIONAL CEMENT STANDARDS

Standards are usually issued on a National basis by the local standardization institute.

Such institutes are ASTM for USA, BSI for UK, DIN for Germany, AFNOR for France, and so on.

Recent formation of large State federations (i.e. the European Community) have brought to a centralized management of standardization, to make it compatible with the free trade of products among countries. The European Committee for standards (CEN) has then rapidly become the main technical reference for all member and affiliated countries in Europe and also in some other areas of the world.

In the context of international standardization of testing methods, even ISO, the International Standards Organization, has simply and directly adopted some of the new documents developed by CEN technical Committees.

As a consequence, the trend all over the world is towards a reduction of the number of standards to a selected minimum, even maintaining some national peculiarities. Therefore we are going to mention here the cement standards that gained worldwide recognition and application, the ASTM and the EN specifications, as well as the Australian standard, an example of a very simple and effective way to draft a technical specification for cement.

People that are interested in a complete compilation of the world cement standards can consult the publication "Cement Standards of the World", issued by Cembureau, Brussels.

3.1 The ASTM Standards

ASTM standards are widely adopted not only in the United States of America, but also in many other countries of Latin America, as well as Asia and Africa.

In the following pages, the specifications contained in the relevant ASTM cement standards are reported

- C 150 - "Standard Specification for Portland Cement"
- C 595M - "Standard Specification for Blended Hydraulic Cements"
- C 1157M - "Standard Performance Specification for Blended Hydraulic Cements".

a) Cements defined by **C 150** are divided in five different types.

- Type **I** — For use in general concrete construction
- Type **II** — For use when exposed to moderate sulfate action, or where moderate heat of hydration is required
- Type **III** — For use when high early strength is required
- Type **IV** — For use when low heat of hydration is required
- Type **V** — For use when high sulfate resistance is required

(Types I to III can also be produced as air-entrained cements, when air entrainment is desired; in this case they bear the suffix "-A").

Table 1 ASTM C150 - Standard Specification for Portland Cement

Cement type →	I	I A	II	II A	III	III A	IV	V
SiO_2, min %	-		20.0		-		-	-
Al_2O_3, max %	-		6.0		-		-	-
Fe_2O_3, max %	-		6.0		-		6.5	-
MgO, max %	6.0		6.0		6.0		6.0	6.0
SO_3, max %								
when C_3A<8%	3.0		3.0		3.5		2.3	2.3
when C_3A>8%	3.5		not applicable		4.5		n.ap.	n.ap.
Loss on ignition	3.0		3.0		3.0		2.5	3.0
Insoluble resid.	0.75		0.75		0.75		0.75	0.75
C_3S, max %	-		-		-		35	-
C_2S, min %	-		-		-		40	-
C_3A, max %	-		8		-		7	5
C_4AF+C_3A, max %	-		-		-		-	25
% air in mortar								
min	-	16	-	16	-	16	-	-
max	12	22	12	22	12	22	12	12
Fineness, m²/g								
turbidimeter	160	160	160	160	-	-	160	160
air permeability	280	280	280	280	-	-	280	280
Autoclave exp.	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Compr. strength MPa 1 day	-	-	-	-	12.0	10.0	-	-
3 days	12.0	10.0	10.0	8.0	24.0	19.0	-	8.0
7 days	19.0	16.0	17.0	14.0	-	-	7.0	15.0
28 days	-	-	-	-	-	-	17.0	21.0
Gillmore setting minutes init.set	60	60	60	60	60	60	60	60
final set	600	600	600	600	600	600	600	600
Vicat setting minutes init.set	45	45	45	45	45	45	45	45
final set	375	375	375	375	375	375	375	375

For special applications, additional chemical and physical requirements are set, e.g.

- Limits on C_3A content for cement types III and III A for moderate (<8%) and high (<5%) sulfate resistance
- limits on the total silicate content (<58%) for types II and II A and heat of hydration for types II, II A, IV and V for low heat cement
- equivalent Na_2O content (<0.6%) for prevention of alkali-aggregate reaction
- 28-day strength when not specified in the main table.

b) Provisions for blended cements in **C 595** are as follows

- Type **IS** - Portland Blast-Furnace Slag Cement (slag content 25÷70%)
- Type **IP** - Portland-Pozzolan Cement (pozzolan content 15÷40%)
- Type **P** - Portland-Pozzolan Cement with low early strength
- Type **S** - Slag Cement (slag content > 70%)
- Type **I(PM)** - Pozzolan-modified Portland Cement (pozzolan content < 15%)
- Type **I(SM)** - Slag-modified Portland Cement (slag content < 25%)

these types can be **MS** (moderate sulfate resistent), **A** (air entrained) or **MH** (moderate heat of hydration).

Table 2a ASTM C595M - Specification for Blended Hydraulic Cement - Composition

Cement type	Clinker + gypsum	BF slag	Pozzolan / fly ash
IS (ev. MS, A, MH)	30 - 75	25 - 70	
S (ev. A)	< 30	> 70	
IP (ev. MS, A, MH)	60 - 85 *		15 - 40
P (ev. MS, A, MH)	60 - 85 *		15 - 40
I (PM) (ev. MS, A, MH)	> 85 *		< 15
I (SM) (ev. MS, A, MH)	> 75	< 25	

* These cements can be produced by blending pozzolan either with ordinary Portland cement or with an IS type cement.

Table 2b ASTM C595M - Specification for Blended Hydraulic Cement - Chemical Requirements

Cement type →	I(SM), I(SM)-A, IS, IS-A	S. S-A	I(PM), I(PM)-A, P, PA, IP, IP-A
MgO, max %	-	-	6.0
SO_3, max %	3.0	4.0	4.0
Sulfide sulfur, max %	2.0	2.0	-
Insoluble resid., max %	1.0	1.0	-
Loss on ignit., max %	3.0	4.0	5.0
Water sol. alkali, max %	-	0.03	-

Table 2c ASTM C595M - Specification for Blended Hydraulic Cement - Physical Requirements

Cement type →	I(SM) I(PM) IS, IP	same with air en.	IS(MS) IP(MS)	same with air en.	S	SA	P	PA
Autoclave exp.	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
A. contraction	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Vicat setting minutes initial hours final	 45 7	 45 7	 45 7	 45 7	 45 7	 45 7	 45 7	 45 7
% air of mortar	12	19±3	12	19±3	12	19±3	12	19±3
Compr.strength min. MPA 3 d 7 d 28 d	 13.0 20.0 25.0	 10.0 16.0 20.0	 11.0 18.0 25.0	 9.0 14.0 20.0	 - 5.0 11.0	 - 4.0 9.0	 - 11.0 21.0	 - 9.0 18.0
Heat of hydrat. kJ/kg max 7d 28 d	 290 330	 290 330	 290 330	 290 330	 - -	 - -	 250 290	 250 290
Water req. %	-	-	-	-	-	-	64	56
Drying shrink.	-	-	-	-	-	-	0.15	0.15
Mortar expans. max % 14 d 8 weeks	 0.02 0.06	 0.02 0.06	 0.02 0.06	 0.02 0.06	 0.02 0.06	 0.02 0.06	 0.02 0.06	 0.02 0.06
Sulfate resist. max exp.180 d	-	-	0.10	0.10	-	-	-	-

c) An interesting example of a performance oriented standard is ASTM **C 1157M**. Here blended cement are classified according to their performance, with no restrictions on the composition of the cement or its constituents.

The specified cement types are based on specific requirements for general use (**GU**), high early strength (**HE**), resistance to sulfate attack (**MS** and **HS**), heat of hydration (**MH** and **LH**), low reactivity with alkali-reactive aggregates (**R**).

Table 3 ASTM C1157M - Performance Spec. for Blended Cement

Cement type →	**GU**	**HE**	**MS**	**HS**	**MH**	**LH**
Autoclave length change, max %	0.80	0.80	0.80	0.80	0.80	0.80
Vicat setting time, minutes						
initial	45	45	45	45	45	45
final	420	420	420	420	420	420
% air of mortar	to be specified on documents to customer					
Compressive strength, min MPa						
1 day	-	10.0	-	-	-	-
3 days	10.0	17.0	10.0	5.0	5.0	-
7 days	17.0	-	17.0	10.0	10.0	5.0
28 days	-	-	-	17.0	-	17.0
Heat of hydration, max kJ/kg						
7 days	-	-	-	-	290	250
28 days	-	-	-	-	-	290
Mortar bar exp. 14 days, max %	0.020	0.020	0.020	0.020	0.020	0.020
Sulfate exp., max % 6 months	-	-	0.10	0.05	-	-
1 year	-	-	-	0.10	-	-
Option R, low ASR reactivity						
expansion 14 days, max %	0.020	0.020	0.020	0.020	0.020	0.020
expansion 56 days, max %	0.060	0.060	0.060	0.060	0.060	0.060
Optional physical requirements						
Early stiffening, final penetration min %	50	50	50	50	50	50
Compressive strength, min. MPa 28 days	28.0	-	28.0	-	22.0	-

3.2 THE EUROPEAN STANDARD ENV 197-1

This standard was issued in the early 90's after some 25 years of drafting, with the aim at including in one and only specification all the cements produced all over Europe. It is clear that the extremely variable climatic, industrial and economic conditions of the continent were the main reason of the huge diversity of binders produced and consequently of the very tough job for the members of CEN to reach a reasonable compromise among member countries.

The ENV 197-1 standard is divided in nine chapters, the most important are

- chapter 4 "Constituents", dealing with cement components; here some main characteristics of the materials to be used in cement production are set
- chapter 5 "Cement types, composition and designation", where the official names and abbreviations are described for every type of cement, according to its composition
- chapter 6, 7, 8 "Mechanical-, Phisical-, Chemical requirements" setting limits for the main cement properties
- chapter 9 "Conformity Criteria", dealing with the procedures to apply for the autocontrol testing of cement and the subsequent evaluation of its conformity to the specifications.

Description of cement components (constituents) in Chapter 4 is very accurate, complete and rigorous, including additional specifications (Table 5) that define the main component characteristics in order to assure their performance in cement.

The ENV 197-1 standard recognizes and legitimates the use of some constituents that have a long tradition of use in many countries, but at the same time are not available in other areas (i.e. natural pozzolan, fly ash, burnt shale). There is absolute freedom, with the exception of Portland cement clinker as the only obligatory constituent, in the choice of materials to produce cements according to ENV 197-1, provided they comply with the requirements of Chapter 4.

This freedom is reflected in Chapter 5 (Table 4), where cement compositions are reported. As many as 25 different types of cements can be produced, using one or more of the indicated constituents.

It is worthwile noting that the relative amounts are in mass-% on the cement nucleus, that is without considering gypsum (since its amount in cement can vary according to purity and optimum gypsum content). Then, for each type of cement the industrial composition shall be calculated *with* the actual gypsum content.

Mechanical, physical and chemical requirements are listed in Table 6 and 7. A significant difference in the strength classification is the subdivision of every main strength class into two subclasses, to differentiate rapid hardening cement from those with normal strength development. This makes the theoretical number of producible cements as high as 150 (25 types x 6 classes)!

Additionally, the upper limit for 28 day strength is also set. This is somewhat a marketing besides technical requirement, it has the advantage to force all producers to keep cement strengths (and quality) within a certain interval and at the same time protects against unfair competition. The drawback is, for some blended cements (high slag content, mainly), the serious difficulty to comply with both the minimum 2-day and the maximum 28-day strength limit, that is often exceeded.

The last chapter introduces a new criterion to evaluate conformity of cement, based on a continuous statistical control (autocontrol).

Cements must fulfill

- conformity criteria on single absolute values
- statistical conformity criteria (according to variables or attributes) on characteristic limits.

This means that for the main parameters, cement must conform to a minimum (or maximum) limit value, as it was previously provided by the standards, and also to a characteristic limit. All results over a six- or twelve month period are evaluated according to the mean value and standard deviation and calculated to yield a consumer's risk lower than 5% (that is the risk that a defective lot is accepted as conforming the standard) for lower strength limits and 10% for the upper one.

To make it simple, let's consider the conformity for 28 day strength. According to ENV 197-1, the following equation shall apply

$x - k_A\, s \geq L$ (lower limit) as well as $x + k_A\, s \geq U$ (upper limit)

where L is the lower (resp. upper) strength limit at 28 days, s is the calculated standard deviation, k_A is the acceptability constant (depending on the number of tested samples).

Now if a cement of mean 28 day strength = 38.0 MPa is produced with s = 2.0 and tested over 110 samples/year (k_A = 1.93 for L and 1.53 for U), the conformity equation for a 32.5 MPa characteristic value will yield a result of

$x - k_A\, s = 38.0 - 2.0 \times 1.93 = 34.1$ MPa, which is higher than 32.5 as well as

$x + k_A\, s = 41.1$ MPa which is lower than 52.5 then the cement is conforming the standard. But a value of s = 3.2 will yield

$x - k_A\, s = 38.0 - 3.2 \times 1.93 = 31.8$ which is lower than 32.5; in this case the cement does not fulfill the standard specification set for minimum late strength.

The following graphs will help to visualize the situation. The first one shows that a "good" cement, with low strength variability (s = 2) fulfill the requirements with an average 28-day strength of 36.4 MPa, while the other refers to a "bad" cement (s = 4) and the necessary average strength to fulfill specs is 40.2 MPa (3.8 MPa higher!).

This approach is quite interesting and innovative, because it comes clear from the proposed example, that a consistent production, with low deviation, can allow for the production of a complying cement with lower mean strength values, that cannot be sufficient if the deviation is higher, thus forcing to raise the average strength to higher and more costly levels.

Figure 1 **Conformity of a "good" cement (s = 2)**

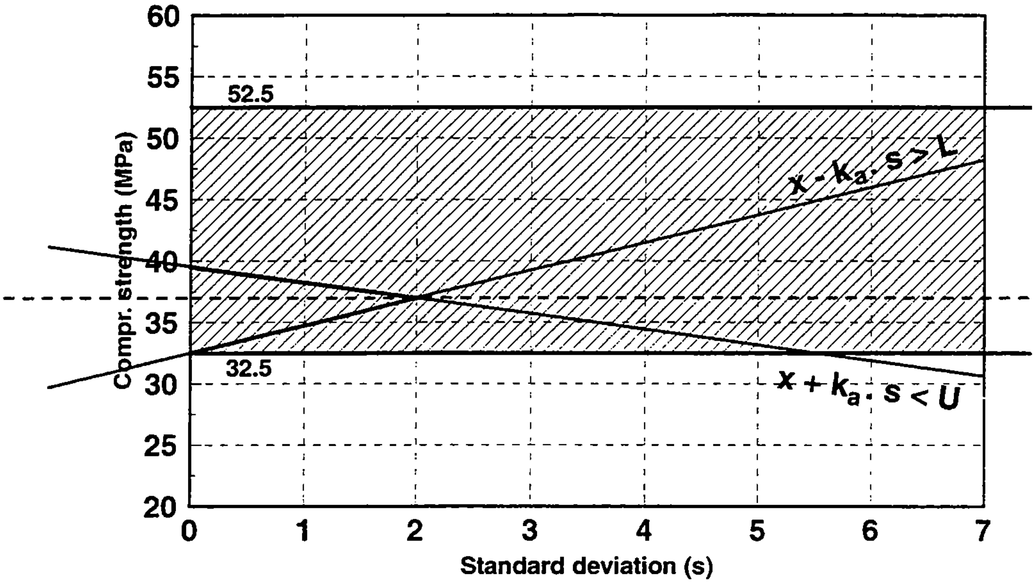

Figure 2 **Conformity of a "bad" cement (s = 4)**

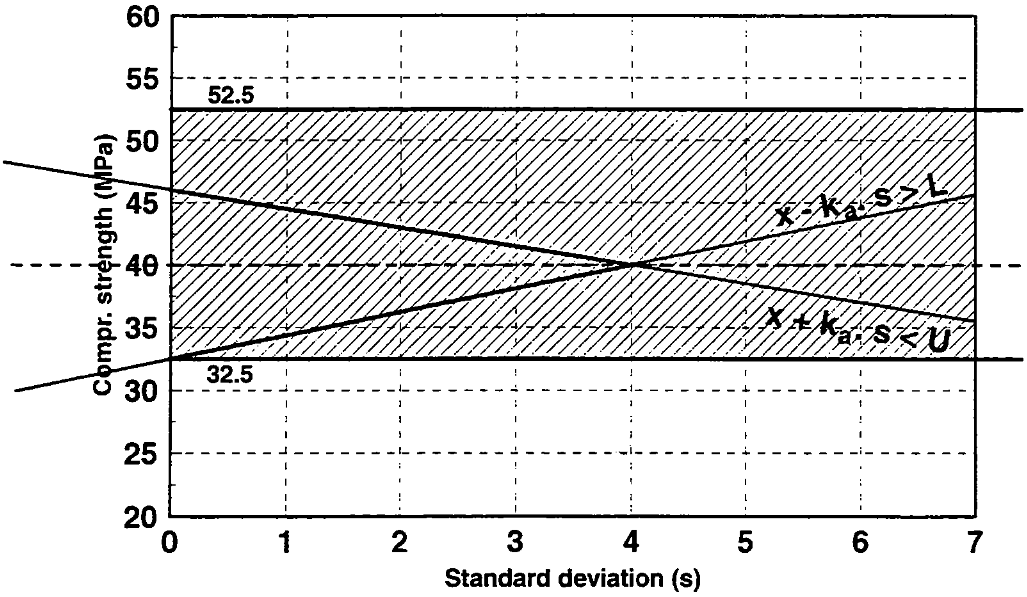

Table 4 **The ENV 197-1 specification on common cements - Cement types and composition**

Cement type	Designation	Abbrev.	Clinker	GGBF slag	Micro silica	Natural pozzol.	Industr. pozzol.	Silic. fly ash	Calcar. fly ash	Burnt shale	Limest.	Other constit.
I	Portland Cement	I	95-100	-	-	-	-	-	-	-	-	0-5
II	Portland Slag Cement	II/A-S	80-94	6-20	-	-	-	-	-	-	-	0-5
		II/B-S	65-79	21-35	-	-	-	-	-	-	-	0-5
	Portland MS Cem	II/A-D	90-94	-	6-10	-	-	-	-	-	-	0-5
	Portland Pozzol. Cement	II/A-P	80-94	-	-	6-20	-	-	-	-	-	0-5
		II/B-P	65-79	-	-	21-35	-	-	-	-	-	0-5
		II/A-Q	80-94	-	-	-	6-20	-	-	-	-	0-5
		II/B-Q	65-79	-	-	-	21-35	-	-	-	-	0-5
	Portland Fly Ash Cement	II/A-V	80-94	-	-	-	-	6-20	-	-	-	0-5
		II/B-V	65-79	-	-	-	-	21-35	-	-	-	0-5
		II/A-W	80-94	-	-	-	-	-	6-20	-	-	0-5
		II/B-W	65-79	-	-	-	-	-	21-35	-	-	0-5
	Portland Burnt Shale Cement	II/A-T	80-94	-	-	-	-	-	-	6-20	-	0-5
		II/B-T	65-79	-	-	-	-	-	-	21-35	-	0-5
	Portland Limest. Cement	II/A-L	80-94	-	-	-	-	-	-	-	6-20	0-5
		II/B-L	65-79	-	-	-	-	-	-	-	21-35	0-5
	Portland Compos Cement	II/A-M	80-94	<---------- 6-20 ---------->								
		II/B-M	65-79	<---------- 21-35 ---------->								
III	Slag Cement	III/A	35-64	36-65	-	-	-	-	-	-	-	0-5
		III/B	20-34	66-80	-	-	-	-	-	-	-	0-5
		III/C	5-19	81-95	-	-	-	-	-	-	-	0-5
IV	Pozzolanic Cement	IV/A	65-89	-	<------ 11-35 ------>				-	-	-	0-5
		IV/B	45-64	-	<------ 36-55 ------>				-	-	-	0-5
V	Composite Cement	V/A	40-64	18-30	-	<----- 18-30 ----->			-	-	-	0-5
		V/B	20-39	31-50	-	<----- 31-50 ----->			-	-	-	0-5

Table 5 ENV 197-1 - Requirements for cement constituents

Type of constituent	Property	Conformity Limit
Clinker	sum of silicates $C_3S + C_2S$	> 2/3 of total
	ratio CaO / SiO_2	> 2.0 %
	MgO content	< 5.0 %
Blast Furnace Slag	glass content	> 2/3 of total
	$CaO + MgO + SiO_2$	> 2/3 of total
	$CaO + MgO / SiO_2$	> 1.0
Fly ash	loss on ignition	< 5.0 %
Siliceous fly ash	reactive CaO	< 5.0 %
	reactive SiO_2	> 25 %
Calcareous fly ash	reactive SiO_2	> 5 %
	28 d strength of ground material	> 10 MPa
	expansion on a 30% blend	< 10 mm
Pozzolans	reactive SiO_2	> 25 %
Burnt shale	28 d strength of ground material	> 25 MPa
	expansion on a 30% blend	< 10 mm
Limestone	$CaCO_3$ content	> 75 %
	clay content (methilene blue test)	< 1.2 %
	total organic carbon (TOC)	< 0.2 %

Table 6 ENV 197-1 - Mechanical and Physical Requirements

Strength class	Compressive strength (N/mm² - MPa)				Initial setting time(min)	Expans. (mm)
	Early strength		Standard strength			
	2 days	7 days	28 days			
32,5	-	> 16	> 32,5	< 52,5	> 60	< 10
32,5 R	> 10	-				
42,5	> 10	-	> 42,5	< 62,5		
42,5 R	> 20	-				
52,5	> 20	-	> 52,5	-	> 45	
52,5 R	> 30	-				

Table 7 ENV 197-1 - Chemical Requirements

Property	Test refer.	Cement type	Strength class	Requirement
Loss on ignit.	EN 196-2	CEM I CEM III	All	< 5.0 %
Insol. residue	EN 196-2	CEM I CEM III	All	< 5.0 %
Sulfates SO_3	EN 196-2	CEM I CEM II CEM IV CEM V	32,5 - 32,5 R 42,5	< 3.5 %
			42,5 R 52,5 - 52,5 R	< 4.0 %
		CEM III	All	
Chlorides	EN 196-21	All	All	< 0.10 %
Pozzolanicity	EN 196-5	CEM IV	All	positive test

After drafting for common cements, CEN is also preparing new specifications for "special cements", such as sulfate resisting and low heat cements. The drafts are in an advanced stage and are likely to be distributed for approval by member States in 1998.

3.3 THE AUSTRALIAN STANDARD AS 3972-1991

This is a good example of how a standard can be drafted in a simple, clear and effective way.

It consists of two pages only, where reference documents, materials and cements are listed and defined, as well as requirements, properties and dispatching conditions.

All one need to know is contained in this astonishingly essential document.

Cement types are defined as follows

- type **GP** - general purpose Portland cement
- type **GB** - general purpose blended cement

while special purpose cements are

- type **HE** - high early strength cement
- type **LH** - low heat cement
- type **SR** - sulfate resisting cement.

A blended cement should contain more than 5 % of mineral addition (fly ash, BF slag, or both).

Specified properties are compiled in Table 8.

Table 8 AS 3972-1991 - Portland and blended cements

Type	Property									
	Setting time		Exp.	SO_3	Compr. strength			Heat hydrat.		C_3A
	min.	max.	max	max	minimum MPa			max. J/g		max
	min	h	mm	%	3 d	7 d	28 d	7 d	28 d	%
GP	45	10	5	3.5	-	25	40	-	-	-
GB	45	10	5	3.5	-	15	30	-	-	-
HE	45	10	5	3.5	20	30	-	-	-	-
LH	45	10	5	3.5	-	10	30	280	320	-
SR	45	10	5	3.5	-	20	30	-	-	5.0

Additional properties such as

- loss on ignition
- fineness or fineness index
- nature and proportion of materials in the cement
- major oxide composition of the cement
- chloride content, if exceeding 0.05 %

can be provided by the manufacturer upon specific request from the purchaser.

3.4 Conclusion

The importance of standards in our technical life and the present situation for cement have been highlighted. The expected trend for cement standards is represented in table 9.

Table 9 World trends in cement standards

Object	Past/present situation	Trend
Number of standardized cements	Few	Increasing number of common and special cements
Mineral components or additions in cement	Not allowed in OPC, limited use of blended cements	Allowed in OPC, increased number of blended cements
Strength	Compressive and flexural	Only compressive str.
Compr. strength limit	Minimum strength requir.	Min. and max. stength
Age of tests	1, 2, 3, 7, 28 days	2 and 28 days
Standard mortar	constant consistency, constant W/C ratio	constant W/C ratio
W/C ratio	different in each country	0.5
Setting time	initial and final settiong t.	initial setting time

4. STANDARDS FOR MINERAL COMPONENTS

Mineral components or additions have always been used in the production of building materials.

In ancient Greece and Rome blends of burnt lime and pozzolan were used for brickworking and building purposes.

Nowadays the use of mineral additions has improved in quantity and quality.

On one hand the available mineral components are quite extensively evaluated and utilized in cement manufacture, for production, cost-effectiveness and environmental purposes, on the other hand the advancement in technology of high performance concrete, in terms of ultra-high early strengths but also high durability, have benefited by the availability of these materials.

Then the more sophisticated uses of mineral components require adequate standards to describe their properties and performance in cement and concrete.

As a matter of fact, mineral components (and other mineral additions) can be mainly used as

- cement constituents, in the production of blended or Portland modified cements
- raw materials in concrete production, as value added products which impart additional characteristics to the cementitious conglomerate.

Recent standardization has covered both of these aspects, and more is expected in the future.

Requirements set forth by standards dealing with cement production (see as an example Table 7 in previous chapter) are usually enclosed in the standard itself; they consider aspects of the chemical composition of mineral components and put sometimes also limits with respect to the hydraulic activity, the main responsibility on the effectiveness of the addition being left on the cement producer's shoulders since he has to comply with the final product requirements.

Standards on materials to be used as main concrete constituents are separate documents. They deal about the same parameters as for cement production, but they are mainly focussed on the impact that these characteristics will have on concrete.

Some examples related to mineral components are reported

- **ASTM C 311** "Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland-Cement Concrete"
- **EN 450** "Fly Ash for Concrete"
- **ASTM C 989** "Specification for Ground Granulated Blast Furnace Slag for Use in Concrete and Mortar
- **ASTM C 1240** "Specification for Silica Fume for Use in Hydraulic Cement Concrete and Mortar.

5. CONCRETE STANDARDS

5.1 Purpose

The purpose of the concrete standards and specifications is to regulate the relations between the different parties involved in the activity of concrete construction.

Besides the interest to regulate the interaction between the different parties, there is a supreme interest of the society to ensure that the constructions are stable, aesthetic and durable. A typical example are the antiseismic codes, which, although they lead to more costly structures, prevent enormous losses of human lives and goods in case of earthquakes compared to structures built in a normal way.

Similarly to cement standards, the responsibility for the emission of the concrete standards varies a lot from country to country. For instance in Germany and Great Britain, this is the responsibility of the national standard entity (DIN and British Standards respectively), whereas in the United States and Switzerland, it is the task of a professional organisation (ACI (American Concrete Institute) and SIA (Society of Engineers and Architects) respectively). In other countries like Italy, it can also be the responsibility of the government through the Ministry of public works.

5.2 Content of the Standards and Specifications

It will be referred here exclusively to the aspects of concrete technology within the wider field of codes, standards and specifications, with a special emphasis on the corresponding prescriptions in use in the United States (ASTM, ACI) and in Europe (ENV 206).

5.2.1 Quality of the Concrete Components

In general, the concrete standards make reference to the respective standards for each of the ingredients (cement, aggregates, water, mineral and chemical admixtures). That is to say it is simply indicated that the components must satisfy the quality requirements established in the mentioned standards. The relevant ASTM and EN standards for the concrete components cement, admixtures and aggregates are listed in the annex.

5.2.2 Quality of Fresh Concrete

The following properties of the fresh concrete are specified:

- consistency/workability (always)
- air content (when air is intentionally entrained)
- temperature (in extreme climates)
- density (for light weight or heavy concrete)
- stiffening rate (in extreme climates or for slip forming)

In general, the constructor specifies the consistency of the concrete adequate for the structural element to be concreted and for the available means of placing and compacting. The concrete producer has to deliver a material which complies with this consistency within a certain tolerance. For instance the ASTM standard C 94 for ready-mix concrete prescribes:

Specified Slump	Tolerance
< 50 mm	± 15 mm
50-100 mm	± 25 mm
> 100 mm	± 40 mm

With respect to the content of intentionally entrained air, the ACI recommends percentages which depend on the severity of exposure of the concrete and the maximum aggregate size. A higher severity and a lower maximum aggregate size correspond to higher percentages of air. The ASTM standard C 94 establishes a tolerance of ± 1.5% for the specified air content.

5.2.3 Strength of Hardened Concrete

The strength is the most important characteristic to be specified for the hardened concrete. In the past, it was common to specify the mean strength of the concrete, so that, if the average of the results of the specimens was equal or greater than the specified values, the strength requirement was considered as fulfilled. Based on this criterion, the following two series were equivalent, since both presented the same average (30 MPa):

Series "A": 32, 28, 34, 29, 28, 30, 32, 28, 29, 30

Series "B": 40, 27, 48, 30, 15, 30, 36, 20, 28, 26

At simple view, it results that the series "A" is better than "B", because its values are more uniform (s = 2 MPa against s = 9 of the series "B"). That is to say, although both comply with the specified mean strength, a structure built with concrete "A" will be safer from the structural point of view than if it is built with concrete "B", as the latter presents a strength result which is only the half of the specified value.

As already mentioned for cement, standards and specifications take into account the variability of concrete and apply the criterion of fractiles to specify the concrete strength. The specified strength corresponds to a fractile related to a certain probability, which means that the designer of the structure accepts that a certain percentage of the produced concrete is "defective". The allowed percentage of "defectives" varies according to the country (it has to be mentioned that the percentage has not necessarily to be related to the safety of the structures):

Percentage p	Country
2 %	Switzerland
5 %	Europe
10 %	United States
20 %	United States (massive concrete)

Assuming that the distribution of strength values follows the law of Gauss, the fractile x_P is calculated as

$$x_P = x_M - z_P \cdot s$$

where z_P is a function of the percentage of "defectives" p. We can see that the mean x_M as well as the standard deviation s participate in this criterion, which explains its universal acceptation.

This principle has now to be applied for the design of the concrete mixes. If we have specified a certain strength that we will denote f'_C (which corresponds to the fractile x_P for a certain percentage of "defectives"), we have to design our mix with a certain margin taking into account the expected variability s_E in the production process. That is to say we have to design the mix for a certain mean design strength f'_D which will be equal to:

$$f'_D = f'_C + \text{margin} = f'_C + z_P \cdot s_E$$

It is evident that the producer which elaborates the concrete in a more uniform manner (lower s_E) will be able to design his mix for a lower strength and therefore more economically.

5.2.4 Durability of Concrete

The traditional criterion to guarantee the durability of the structures against attack of the environment has been the establishment of limits with respect to concrete composition. For instance ENV 206 and ACI code 318 for reinforced concrete establish limits regarding the w/c-ratio of the concrete in function of the exposure condition to which the structure will be submitted, trying to control concrete permeability to improve its durability against aggressive agents.

The fundamental problem of such type of specification is that it is often omitted at the moment of ordering the concrete and anyway its interpretation is unclear (are they mean values, absolute maximums, fractiles?). Moreover, its compliance is very difficult to verify in practice (how is the w/c-ratio of a concrete determined?). The same criticism can be made with respect to the project of the European Standards, where, apart from the maximum w/c-ratio, also a minimum cement content is specified.

A more practical criteria is the one established in the Australian Standards, where, instead of fixing limits for the concrete composition, a minimum strength is specified according to the type of exposure to which the structure will be submitted. The advantage of this criterion is that it is more easy to interpret and to verify its compliance in practice.

5.3 The European Standard ENV 206

Most discussions on concrete standards are concentrated on the issue of concrete durability, and in this context the specifications on cement content, water cement ratio, chloride content and alkali aggregate reaction.

The durability aspects are here discussed in connection with the new ENV 206 draft „Concrete. Performance, production, placing and compliance criteria", which was issued as a prestandard in 1989. The development of this standard has a similar history to the EN cement standard; the CEN Committee TC 94 started work in 1981, and the present draft is far from being the final version. Nevertheless, it is a good review of the present state of knowledge on the topic, comprising a consensus of expert opinions in Europe.

ENV 206 should cover concrete in general; for all types of concrete - site, precast and ready mixed concrete, plain, reinforced and prestressed concrete. For special purposes, however, additional specifications may be needed, and for these reference is made to the individual national standards. The standard also makes reference to other European standards as regards types of cements, aggregates, mineral and chemical admixtures.

5.3.1 Cement Content and Durability

The minimum cement content in steel reinforced concrete is specified according to environmental conditions and type of concrete structure; it varies between 260 to 300 kg/m^3, as shown in tables 10 and 11.

Table 10 Exposure Classes related to Environmental Conditions

Exposure Class			Examples of Environmental Conditions
1	Dry environment		interior of dwellings or offices [1]
2	Humid environment	a without frost	- interior of buildings where humidity is high (e.g. laundries) - exterior components - components in non-aggressive soil and/or water
		b with frost	- exterior components exposed to frost - components in non-aggressive soil and/or water and exposed to frost - interior components where the humidity is high and exposed to frost
3	Humid environment with frost and de-icing agents		interior and exterior components exposed to frost and de-icing agents
4	Seawater environment	a without frost	- components completely or partially submerged in seawater or in the splash zone - components in saturated salt air (coastal area)
		b with frost	- components partially submerged in seawater or in the splash zone and exposed to frost - components in saturated salt air and exposed to frost
The following classes may occur alone or in combination with the above classes:			
5	Aggressive chemical environment [2]	a	- slightly aggressive chemical environment (gas, liquid or solid) - aggressive industrial atmosphere
		b	moderately aggressive chemical environment (gas liquid or solid)
		c	highly aggressive chemical environment (gas, liquid or solid)

1) This exposure class is valid only as long as during construction the structure or some of its components is not exposed to more severe conditions over a prolonged period of time

2) Chemically aggressive environments are classified in ISO 9690. The following equivalent exposure conditions may be used:
   * Exposure class 5a: ISO classification A1G, A1L, A1S
   * Exposure class 5b: ISO classification A2G, A2L, A2S
   * Exposure class 5c: ISO classification A3G, A3L, A3S

Table 11 Durability Requirements related to Environmental Exposure

Requirements	Exposure Class according to Table 2								
	1	2a	2b	3	4a	4b	5a	5b	5c[1]
Max. w/c ratio for [2]									
- plain concrete	-	0.70							
- reinforced concrete	0.65	0.60	0.55	0.50	0.55	0.50	0.55	0.50	0.45
- prestressed concrete	0.60	0.60							
Min. cement content [2] in kg/m^3 for									
- plain concrete	150	200	200				200		
- reinforced concrete	260	280	280	300	300	300	280	300	300
- prestressed concrete	300	300	300				300		
Min. air content of fresh concrete in % for nominal max aggregate size of [3]			[4]	[4]		[4]			
- 32 mm	-	-	4	4	-	4	-	-	-
- 16 mm	-	-	5	5	-	5	-	-	-
- 8 mm	-	-	6	6	-	6	-	-	-
Frost resistant aggregates [6]	-	-	yes	yes	-	yes	-	-	-
Impermeable concrete according to clause 7.3.1.5	-	-	yes	yes	yes	yes	yes	yes	yes
Types of cement for plain and reinforced concrete according to EN 197							sulfate resisting cement [5] for sulfate contents > 500 mg/kg in water > 3000 mg/kg in soil		
	These values of w/c ratio and cement content are based on cement where there is long experience in many countries. However at the time of drafting this pre-standard experience with some conditions in some countries. Therefore during the life of this pre-standard, particularly for exposure classes 2b, 3, 4b the choice of the type of cement and its composition should follow the national standard or regulations valid in the place of use of the concrete. Alternatively the suitability for use of the cements may be proved by testing the concrete under the intended conditions of use. Additionally cement CEI may be used generally for prestressed concrete. Other types of cement may be used if experience with these types is available and the application is allowed by the national standards or regulations valid in the place of use of the concrete.								

1) In addition, the concrete shall be protected against direct contact with the aggressive media by coatings unless for particular cases such protection is considered unnecessary.
2) For minimum cement content and maximum water/cement ratio laid down in this standard only cement listed in clause 4.1 shall be taken into account. When pozzolanic or latent hydraulic additions are added to the mix, national standards or regulations, valid in the place of use of the concrete, may state if and how the minimum or maximum values respectively are allowed to be modified.
3) With a spacing factor of the entrained air void system < 0.20 mm measured on the hardened concrete.
4) In cases where the degree of saturation is high for prolonged periods of time. Other values or measures may apply if the concrete is tested and documented to have adequate frost resistance according to the national standards or regulations valid in the place of use of the concrete.
5) The sulphate resistance of the cement shall be judged on the basis of national standards or regulations valid in the place of use of the concrete.
6) Assessed against the national standards or regulations valid in the place of use of the concrete.

These requirements reflect the generally accepted opinion that the durability of steel reinforced concrete is governed mainly by its porosity and thus strongly affected by the w/c ratio and cement content.

An important feature of the standard is the differentiation of the cement content according to the severity of its exposure. This allows the concrete producer to use their skills and knowledge in order to design concrete mixes more economically. A prerequisite of this differentiation is, of course, that information on the different conditions to which the specific concrete job is subjected is available.

The prescription of cement content and w/c ratio has some problems: It is difficult to determine both of them in fresh and hardened concrete for control purposes. Furthermore, concrete durability depends not only on cement content as a w/c ratio, it is affected as well by the care taken in its transport, placing, compacting and curing. Therefore, it is indispensable that the quality of concrete in the construction after placing and curing is tested. We know that the porosity of a concrete governs nearly all aspects of durability. Therefore, investigations are under way to introduce a test method enabling the measurement of the porosity of the concrete from specimens taken from the hardened concrete structure. It consists of measuring the amount of gas which flows through the pore system of the concrete specimen in a unity of time. By so measuring the porosity, not only is care taken by the concrete producer, but also that of the contractor placing, compacting and curing the concrete is checked.

An alternative way of testing the porosity and additional aspects of the concrete micro-structure is the microscopical examination of very small specimens. It is very useful for a qualitative inspection of concrete quality, however, it seems difficult to apply this method for a quantitative assessment in the framework of a standard.

5.3.2 Chloride Content

The maximum chloride content in concrete permitted in plain, reinforced and prestressed concrete is shown in table 12.

Table 12 Maximum Chloride Content of Concrete

Concrete	C1- by Mass of Cement
Plain concrete	1%
Reinforced concrete	0.4%
Prestressed concrete	0.2%

The relatively high content of chloride permitted in steel reinforced concrete, reflects the results of recent investigation, which show that no corrosion of steel is expected at a chloride content of 0.4% by mass of cement. Similar soft limits are prescribed in the ACI standards as shown in table 13.

Table 13 Chloride Content in Concrete, ACI 318-83

Maximum water-soluble chloride ion concentrations in hardened concrete at an age of 28 days contributed from the ingredients including water, aggregates, cementitious materials and admixtures	
Type of Member	**Limit (by mass of concrete)**
Prestressed concrete	0.06
Reinforced concrete exposed to chloride in service	0.15
Reinforced concrete that will be dry or protected from moisture in service	1.00
Other reinforced concrete construction	0.30

5.3.3 Alkali Aggregate Reaction

To prevent deterioration of concrete due to alkali aggregate reaction, it is recommended to apply one or more of the following measures:

- Limit the total alkali content of the concrete mix
- Use a cement with a low effective alkali content
- Change the aggregates
- Limit the degree of saturation of the concrete e.g. by impermeable membranes

Unfortunately no mention is made of the effective measures of using blended cements or mineral admixtures.

5.3.4 Maintenance

Finally, the author would like to point out one serious deficiency of concrete standards; it is the lack of specifications on maintenance of concrete. This is becoming recognized as a gap and attempts are being made to bridge it. Of course this means turning away from the opinion the cement producers have frequently promoted in the past, that concrete need no maintenance whatsoever.

5.4 Referenced documents

5.4.1 Relevant ASTM Standards for Concrete Components

5.4.1.1 Cement

C 150 Specification for Portland Cement

C 595 Specification for Blended Hydraulic Cements

C 1157 Performance Specifications for blended Hydraulic Cements

5.4.1.2 Admixtures

C 260 Specification for Air-Entraining Admixtures for Concrete

C 494 Specification for Chemical Admixtures for Concrete

C 618 Specification for Fly Ash and raw or Calcined Natural Pozzolan for Use as Mineral Admixture in Portland Cement Concrete

5.4.1.3 Aggregate

C 33 Specification for Concrete Aggregates

C 330 Specification for Lightweight Aggregates for Structural Concrete

C 331 Specification for Lightweight Aggregates for Concrete Masonry Units

C 332 Specification for Lightweight Aggregates for Insulating Concrete

C 637 Specification for Aggregates for Radiation-Shielding Concrete

5.4.2 Relevant EN Standards for Concrete Components

5.4.2.1 Cement

ENV 197-1 Common Cement

ENV 197-X Low-heat Cement

ENV 197-Y Sulfate resisting Cement

5.4.2.2 Admixtures

EN 480 Admixtures for Concrete, Mortar and Grout. Test Methods

EN 934 Admixtures for Concrete, Mortar and Grout

5.4.2.3 Aggregates

EN 932 Tests for General Properties of Aggregates

EN 933 Tests for Geometrical Properties of Aggregates

EN 1097 Tests for Mechanical and Physical Properties of Aggregates

EN 1367 Tests for Thermal and Weathering Properties of Aggregates

EN 1744 Tests for Chemical Properties of Aggregates